SLIGHTLY MORE MODERN BUBBLE CHAMBERS

W. D. Walker
University of Wisconsin

ABSTRACT

A review of the state of the art as to rapid-cycling bubble chambers is given. A chamber is proposed for NAL (1.5 meters × 0.5 × 0.5 meters^2 with 40-50 kG and 30-50 cps). A proposal for the use of such a chamber would indicate the possibility of doing 100 events/μb experiments with reasonable effort.

Introduction and Review

Since the construction of the 72-in. and 80-in. bubble chambers there has been relatively little progress in the technology of bubble chambers. The basic reason is that the physics community has been quite satisfied with the operation of bubble chambers. Most bubble chamber users are quite uninterested in details of bubble-chamber technology.

As the energy range has gone up the difficulties associated with bubble-chamber analysis have gone up almost linearly with time. Part of the difficulties have been due to the success in the past, as more detailed information has been demanded. The number of pictures required for a given experiment is now at the 10^6 picture level. Another bottleneck is in the analysis capability of the various groups. Essentially the event filtering is done by the analysis systems. Thus what one would like to have at NAL (and indeed today), is a system whereby some degree of filtering can be done long before the final analysis. This sort of goal leads one to the idea of a hybrid system. To begin with it would be desirable to have some filtering on-line in making rudimentary decisions as to whether to flash the lights. Any such scheme demands a more efficient use of bubble chambers than has heretofore been possible.

I will first review what has been done in bubble-chamber development in the recent past.

1. PPA Chamber--This chamber was begun by Ted Bowen and Henry Blumenfeld about 1960 and was used up until last year. The chamber was 15 in. in diameter and used a piston expansion driven by gas. It was designed to run at 20 cps and in fact

would run at 5-7 cps. The gas-driven system plus the piston expansion seem to be the limiting factors in this chamber.

2. MURA Chamber--This chamber was begun in 1960 and used the technology of 1958-1960 in design and construction. This chamber is expanded by three relatively small pistons. The total expansion time is the order of 40 msec. This chamber has been pulsed at a rate of 10 cps in bursts of 3 cycles separated by 1/2 second.

SLAC Development

In the last year at SLAC a group under the direction of J. Ballam has started a major research program aimed at the technology of small chambers. The aim has been to produce a really rapid-cycling chamber. The members of the group have been H. Barney, S. St. Lorant, A. Rogers, and for six months, the author. Two small chambers have been built and operated. These chambers are 2 in. and 4 in. in diameter. The basic design of both chambers is as shown in Fig. 1. These chambers have been successfully run at 90 cps.

Let me give the characteristics of the operations of these chambers. The hydrogen is run at a relatively high temperature (90-100 psi). The chamber plus driver (shake table) had a resonant frequency of about 100 cps. The simplest operation was obtained at a frequency of $\nu_{Res.}/2$, i.e., 40-60 cps. The pressure trace appeared something like Fig. 2. The sort of characteristic pressures were:

Vapor Pressure	90-100 psi
Over Pressure	105-125
Pressure Swing	±50

When one operates the chamber in a resonant sinusoidal mode, difficulties appear. It should be noted that the sinusoidal mode of operation is the most convenient as relatively little power is required to drive the system. The difficulty has to do with the lack of time for recovery between expansions. Bubbles grow rapidly and disappear slowly. Any sort of leak or plume into the chamber will produce a regenerative situation in which the plume boiling absorbs the expansion energy and the chamber turns to froth. The expansion piston stroke is close to the theoretical value of 20 mils. A leak or plume destroys the Q of the system and the stroke amplitude immediately collapses.

If the valves are tight and there is no plume, then sinusoidal operation appears possible. The sinusoidal and indeed all of these experiments have required the use of high temperatures. The surface tension is less at high temperature and consequently bubbles grow with smaller pressure drop.

CERN Program

A group at CERN has managed to produce a small He chamber that was expanded by means of a standing ultrasonic wave. This might be a useful technique but it has the following drawbacks:

1. The bubbles grow by resonant absorption until $\lambda \sim r_b$; then the bubbles break up. One thus sees bubble clusters in the pictures.

2. The tracks have gaps in them as nucleation occurs only at anti-nodes. Helium requires only a few psi pressure swing for sensitivity. This is a plus for He but makes H_2 difficult to do.

High power levels can be delivered now by piezoelectric crystals, and it is certainly worth further exploration. I personally am not very optimistic about the chances of producing a macroscopic chamber in this fashion. A Russian group has used a combination of ultrasonic and mechanical piston. This might be a useful combination for hydrogen in that crevasse or surface boiling would be small.

Future Chambers

At the present time a really superior chamber could be built. The superiority could come in two ways:

1. High magnetic field
2. High pulse rate.

These two things are to a certain extent coupled in that eddy-current effects would probably tend to limit the pulse rate. It is likely that one can build sizeable structures mainly of plastics. The British group at Nimrod have developed a plastic Ω type bellows of 1-ft diameter. Such bellows have been cycled several million times successfully.

The cycle rate can in principle be quite high. Let's consider a cylindrically-shaped chamber as shown in Fig. 3. The spring constant of such a chamber would be given by the following:

$$\Delta F = \Delta p\, A$$

$$= -K\, \Delta \ell$$

$$K = \frac{(\Delta p) \cdot 10^6 \cdot \pi r^2}{(0.01) \cdot \ell} = (\Delta p) \cdot 10^8 \cdot \frac{\pi r^2}{\ell} .$$

K is in dynes/cm if Δp is in atmospheres, ℓ, r in cm. The mass of the push bar system and back plate goes something like r. Then

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{\sigma \pi r^2}}$$

$$\omega = \sqrt{\frac{\Delta p \times 10^8}{\ell \sigma}}$$

σ = weight/area of cylinder for the back plate and driving mechanism, $\approx$ 50 g/cm^2,
$\omega = 5\times 10^2$ for an ℓ of 10 in.,
f = 80 cps.

This sort of resonant frequency has been achieved for the small SLAC chambers. We are currently building a 14-in. chamber at Wisconsin with this frequency as a goal. Existing bubble chambers have frequencies of 1/2 to 1/4 this value. The characteristic frequency goes like $1/\ell$ and consequently it is easier to build a thin than a thick chamber. For the cylinder shown the maximum piston velocity would be $\omega\,\delta\ell_0$ where $\delta\ell_0$ = maximum stroke $\approx 0.01\ell$. For the proposed Wisconsin chamber

$$v \approx 5\,\ell \text{ cm/sec} = 100 \text{ cm/sec},$$

The scale velocity (i.e., the velocity of a free liquid surface in a cylinder upon release of pressure; see report by Walker SS-10) for a chamber of this sort is

$$\frac{\delta\ell_0}{\ell}\, v_s = 0.005 \qquad v_s = 5\times 10^2 \text{ cm/sec}.$$

The scale velocity is considerably greater than the proposed maximum velocity.

Practically,the difficulties with building such a chamber have to do with the ability to stroke the piston. A high-pressure hydraulic system seems to be the best way currently available. Commercially available spool valves will operate satisfactorily up to frequencies of 100 cps. A sinusoidal excitation can also probably be obtained electromagnetically for even a 15-in. or 20-in. diameter chamber.

I believe that with existing technology it would be possible to build a 40-in.-50-in. diameter chamber at a cycle rate of 40 to 100 cps. If one used superconducting coils one could have a 40-50 kG field and reasonable access to the chamber. With such a chamber one could study processes with cross sections of the order of 10 μb at the 1000 event level. Thus one could do the A_2 in the 10-BeV region with 1000 events per 20-MeV bin with a modest effort in picture taking.

Analysis Problems

It is important not to confuse the picture-taking rate and overall picture analysis rates. If the bubble-chamber enterprise is to be useful in the future, data acquisition must be improved by at least an order of magnitude. It would be necessary to have a considerable fraction of the analysis on line.

As an example let's consider the simple reaction $\pi^- + p \to \pi^- + N^*$ which will be a simple diffractive isobar production. A relatively small aperture magnet system will measure the momentum and angle of the outgoing π^-. A reasonable trigger would be to demand a fast negative outgoing particle. Thus we might have 100-BeV pions incident and demand 50 to 100-BeV pions out. The outgoing momentum is measured external to the rapid-cycling chamber. The beam could be programmed as shown in Fig. 4. The excitation of N^*'s up to an invariant mass of 5 BeV could be studied in a 1-1.5 meter bubble chamber with high precision. One would probably take nearly every picture if one accepted elastic scatterings in the trigger. About every third picture would have an event of interest. At a cycle rate of 50 cps one could obtain 25 expansions per flattop. This would mean ~250 events per minute. The momentum of the fast pion, the N^* mass, the momentum transfer could be printed on the particular picture, after each accelerator pulse. Thus it would be possible to make qualitative cuts at an early stage in the analysis. The chamber would be used for the slow track analyses ($p_{max} \leq 10$ BeV).

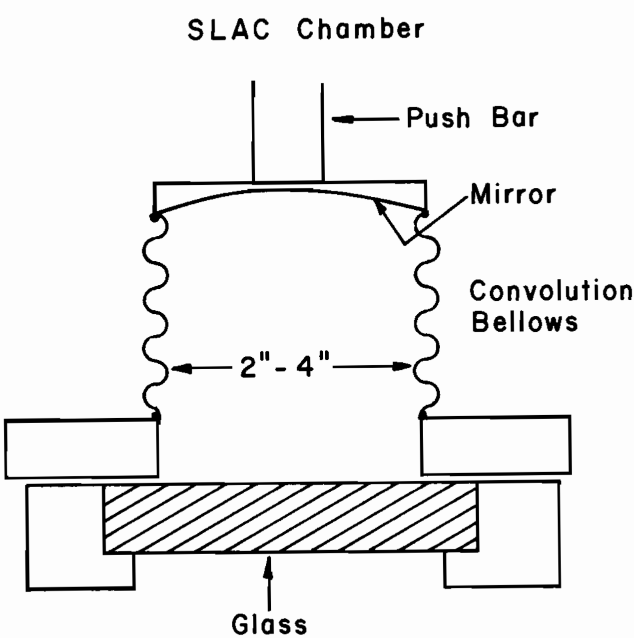

Fig. 1. Diagram of SLAC fast-cycling chamber.

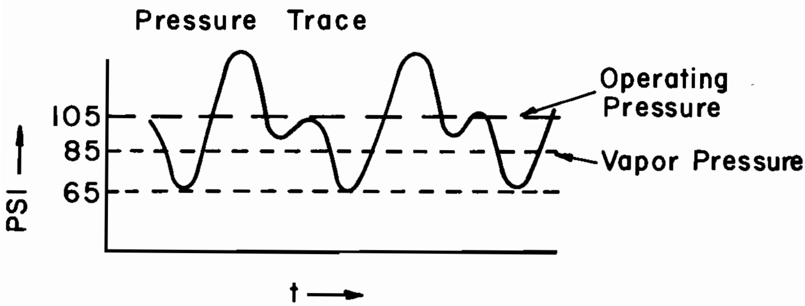

Fig. 2. Pressure cycle of SLAC fast-cycling chamber.

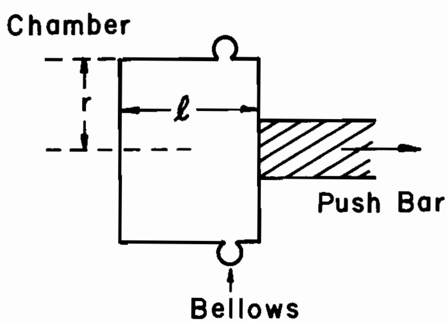

Fig. 3. Design for fast-cycling chamber.

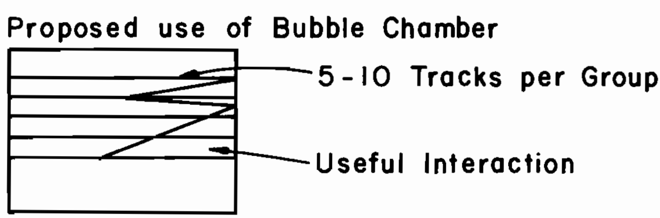

Fig. 4. Beam programming for fast-cycling chamber.